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Contact metallurgy optimization for ohmic contacts to InP

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Abstract

AuGeNi and AuZnNi metallizations to n- and p-InP were studied as a function of the annealing temperature in a Rapid Thermal Annealing (RTA) system. For n-InP (S:8×10^{18} cm^{-3}) a broad minimum existed from 385°C to 500°C, in which the specific contact resistance, r_c, was about 10^{-7} Ωcm^2. The lowest value of 7×10^{-8} Ωcm^2 for n-InP occurred after RTA for 20 sec. at 450°C. For p-InP (Zn:5×10^{18} cm^{-3}) the lowest value of r_c, 7×10^{-6} Ωcm^2, was obtained for AuZn without any Ni. Metallurgical investigations indicated, that low r_c values were associated with interfacial reactions and the formation of stable barrier-lowering metal-phosphides.

1. EXPERIMENTAL

AuGe/Ni/Au layers on (100) n-InP (S:8×10^{18} cm^{-3}) were deposited to a thickness of 1000/250/500 Å by evaporation and RF sputtering. Evaporated Au-12wt%Ge is not homogeneous in depth, a thin Ge layer forms on top. AuZn, Au/AuZn and AuZn/Ni/Au layers on (100) p-InP (Zn:5×10^{18} cm^{-3}) were prepared to thicknesses of 1000 Å, 200/1000 Å and 1000/250/500 Å, respectively. Evaporated Au-10wt%Zn is also not homogeneous, but forms a two-layer structure with a Au layer lying above a Zn layer. The contact areas, ranging from 100-2000 μm^2, were defined by standard lithography. The heat treatment was performed in Ar in a Heatpulse 410 RTA system. The temperature was varied from 300°C to 500°C, and the annealing time was 20 sec. The measurement of the specific contact resistance, r_c, was done using the Cox and Strack technique. Metallurgical investigations included Differential Scanning Calorimetry (DSC) for thermal analysis, X-Ray Diffraction (XRD) for phase identification, Rutherford Backscattering Spectrometry (RBS) for depth resolution of elements and Scanning Electron Microscopy (SEM) for near-surface imaging.

2. RESULTS

The contact experiments to n-InP showed that a broad minimum exists from 385-500°C, where the value of r_c is about 10^{-7} Ωcm^2 (Fig. 1). Note that there is a significant hump in r_c at 415°C. The lowest value, 7×10^{-8} Ωcm^2, occurs after an annealing at 450°C for 20 sec.

The results of the contact experiments to p-InP are shown in Fig. 2. For the AuZn and the Au/AuZn metallizations r_c is minimum after an annealing at 440°C; 7×10^{-6} and 1.4×10^{-5} Ωcm^2, respectively. Note, that the onset temperature for low specific contact resistance is low-

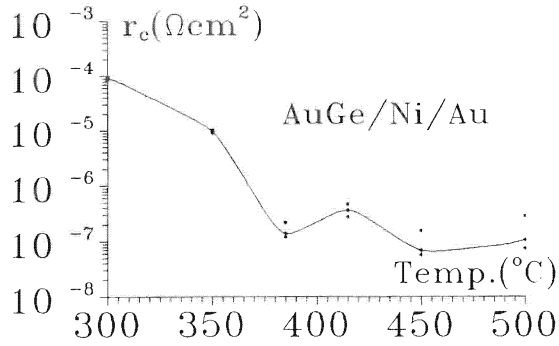


Fig. 1. r_c vs. ann.temp. for AuGeNi/n-InP.

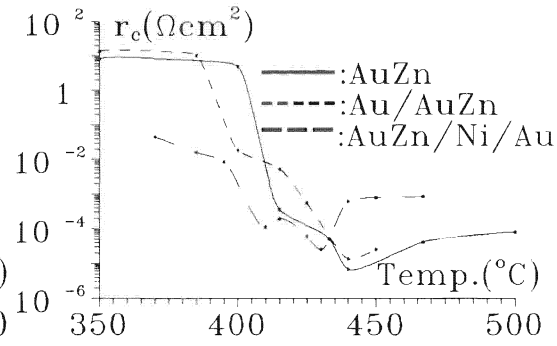


Fig. 2. r_c vs. ann.temp. for AuZn(Ni)/p-InP.

ered by adding the Au layer below the AuZn. However, the lowest obtainable specific contact resistance for the Au/AuZn layer is two times larger than for the AuZn layer alone. From Fig. 2 it is also seen, that the addition of Ni alters the temperature dependence of r_c quite drastically. Below 425°C r_c is lower than for the AuZn layer alone, but again, as for the AuGeNi/n-InP system, there is a hump at 415°C . The r_c minimum 2.7×10^{-5} Ωcm^2 occurs at 430°C. Above 430°C r_c increases abruptly to about 10^{-3} Ωcm^2.

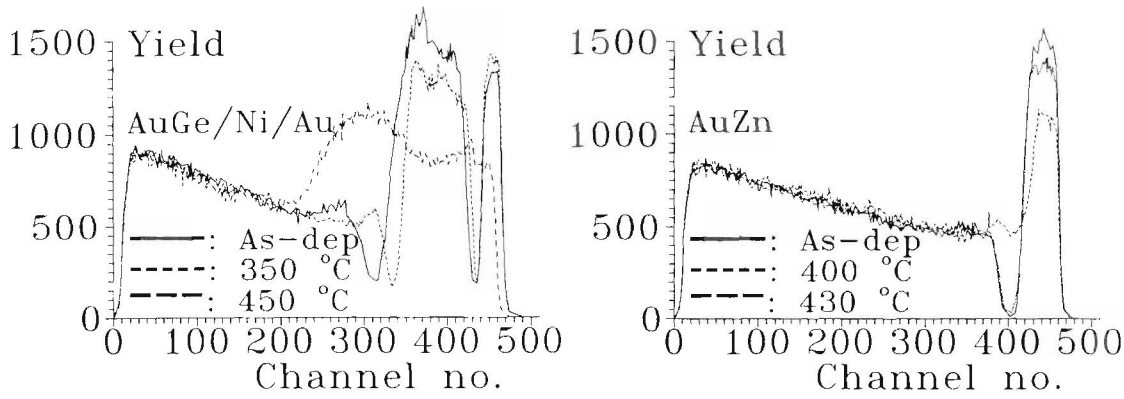
The metallurgical investigations showed, that the onset of low values of r_c were associated with interfacial reactions between the InP and the AuGeNi or AuZn(Ni), respectively. Examples of this are shown in Fig. 3 and 4, where RBS plots and SEM pictures of AuGeNi and AuZn reactions with InP are shown. The as-deposited layers were smooth and uniform (SEM) and there was no intermixing of the elements (RBS). From DSC of the AuGeNi/InP structure two independent and overlapping exothermic peaks ranging from 200-260°C and 240-370°C were identified. The termination of the last peak and the onset of minimum r_c coincides quite well. For AuZn, the Zn redistributes below 400°C because of the low heating rate of the applied DSC instrument (50°C/min. compared to 100°C/sec. of the RTA system), and therefore a DSC experiment involving AuZn will be incorrect in determining the onset temperature for RTA reactions. By XRD various Au-In phases were identified: At 440-450°C annealing a pink Au_3In phase formed (Fig. 4a) and at 465°C a combination of Au_3In and Au_9In_4. At 500°C annealing an eutectic melting of AuIn and $AuIn_2$ was detected (Fig. 4b).

3. DISCUSSION

It is apparent from the electrical characterization, that r_c exhibits an overall minimum for both AuGeNi, AuZn and Au/AuZn around 440-450°C, while for the AuZnNi system there is an abrupt increase in r_c around 440°C. In this section the role of the metallization elements are discussed individually.

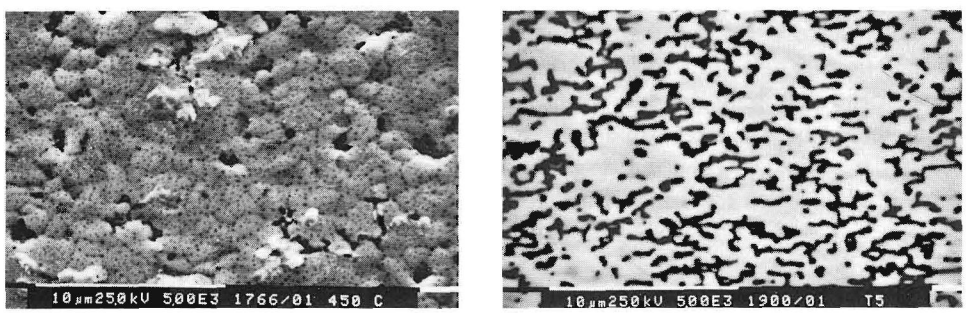
The role of Au

Au is perhaps the most important element to be discussed, since this is the element that governs the degradation of InP most extensively. Many authors have studied the Au-InP system[1-3], and a general path in the degradation process may be constructed. Up to 12.7 at% In is soluble in Au, and this Au(In) solution is the first step in the process. The next step is the



a) *b)*

Fig. 3. RBS plots of a) AuGeNi/n-InP and b) AuZn/p-InP reactions.



a) *b)*

Fig. 4. SEM-picture of a) AuGeNi/n-InP annealed at 450°C for 20 sec. and of b) AuZn/p-InP annealed at 500°C for 20 sec.

formation of Au-In phases. Referring to the Au-In binary system[1] and the Au-In-P ternary system[2] these are the ε- and γ-phases (Au_3In and Au_9In_4). Further degradation leads to higher-order Au-In phases, but there is some uncertainty about the next phases to be formed. We have detected a AuIn-$AuIn_2$ eutectic melting at 500°C, with no other Au-In phases present between this and the γ-phase. Au and P can only form one phase, the metastable Au_2P_3. Formation of both Au-In phases and Au_2P_3 only occurs, when the ε-phase is formed. For other Au-In phases, P either evaporates or is left at the interface between the metals and the InP[3].

The lowest r_c for n- and p-InP (430-450°C annealing) coincides with a poor morphology and growth of Au_3In. In order to improve this morphology, it is an advantage to involve a melting of the Au_3In phase ($T_{melt}\approx 495$°C). A better morphology is also expected to lower r_c even further. Therefore an experiment was made in which Au_3In was grown at 370°C in a conventionel oven and subsequently melted in the RTA system at 500°C for a few seconds. Due to some uncertainty in the annealing time required for growing the Au_3In 20, 40 and 90 min. were tested. Annealing for 40 min. gave the lowest r_c value, 5×10^{-8} Ωcm², and an almost total coverage of the pink Au_3In phase.

The role of Ge and Zn

Ge and Zn are generally assumed to act as donors and acceptors, respectively, in InP, and they are thought to replace In in the lattice. Various authors have shown the formation of compounds involving Ge or Zn adjacent to the InP surface. For Ge, a ternary AuGeP phase is observed[5], and it is shown that this phase actually lowers the barrier height to 0.15 eV. Zn is shown to react with P, creating ZnP phases[4], but there is no information on the electronic properties of these compounds with respect to p-InP.

The role of Ni

Ni is important in obtaining low values of r_c for n-InP (Fig. 1), but for p-InP (Fig. 2) the use of Ni causes an abrupt increase in r_c at 440°C. For a AuZn structure without Ni, r_c is minimum at this temperature. Thus, it seems that the electronic properties at the interface changes, and that the changes are associated with phase formations. It has been shown[5-7], that free Ni diffuses through the Au(Ge/Zn) layer to the InP surface, where Ni(Ge/Zn)P phases eventually form. These NiP phases, associated with the exothermic peak from 240-370°C, are responsible for the changes in the electronic properties[8,9]. For n-InP the barrier height decreases to 0.1 ± 0.1 eV when NiP phases are formed[8,9], while the barrier height for p-InP increases. This partly explains the appearance of the curves in Fig. 2. r_c is lower for Ni containing contacts below 425°C for p-InP, because Ni lowers the reaction temperature. The hump at 415°C for both AuZnNi and AuGeNi contacts to InP are propably associated with two different phase formation regimes due to the addition of Ni. In the first regime, Ni reactions govern the value of r_c. In the second regime, reactions between Au and InP preferentially occur, creating first the Au(In) solution with less P for Ni-P or Zn-P reactions and later Au_3In with more P adjacent to the InP surface for Ni-P or Zn-P reactions.

4. CONCLUSION

The formation of a Au_3In phase during annealing is essential for obtaining low-resistance ohmic contacts to both n- and p-InP using conventional AuGeNi and AuZn metallization schemes. By growing this phase, a considerable amount of phosphorous will be present at the interface between the metallization and the InP for energetically favorable reactions with Ge, Ni, NiGe and AuGe for n-InP and with Zn or AuZn for p-InP. These metal-phosphides, being thermodynamically stable, lowers the Schottky barrier height, normally believed to be pinned at a certain value, and ensures excellent low-resistance ohmic contacts.

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